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# NASA TECH BRIEF

## Lewis Research Center



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### Equations to Assess the Impact Resistance of Fiber Composites

Impact resistance is an important aspect in the design of components made from fiber composite structural materials. Although some basic work on the impact resistance of these materials had been reported, the understanding of impact resistance of fiber composites had not advanced sufficiently for structural components to be designed with predictable impact resistance. Recently, however, equations to assess the impact resistance of fiber composites and convenient design procedures have been developed which are a significant step in this direction. The following two such equations were derived using composite micromechanics and structural mechanics concepts. Equation (1), for longitudinal impact resistance, applies to screening fibers used in composites for impact applications. Equation (2) corresponds to a design concept, referred to as the "hybrid composite concept." It is shown below applied to a cantilever to illustrate the various mechanisms available in this design concept to absorb impact energy. Both equations are applicable to unidirectional composites.

#### Longitudinal Impact Resistance

The longitudinal impact resistance is often expressed as the impact energy density (IED). IED values of composites with a ratio of fiber modulus to matrix modulus ( $E_f/E_m$ ) greater than twenty is given by:

$$\text{IED} = \frac{(1 - k_v) k_f \beta_{fT}^2 S_{fT}^2}{2E_f} \quad (1)$$

with an approximation error of less than five percent. In this equation,  $k_v$  and  $k_f$  denote void and fiber volume ratios, respectively;  $\beta_{fT}$  is the translation coefficient or ratio of fiber tensile strengths in and out of the composite and is taken as unity if not known;  $S_{fT}$  is the

fiber tensile strength out of the composite ( $f$  denotes fiber and  $T$  denotes "under tension"); and  $E_f$  is the longitudinal fiber modulus.

Potential impact resistance of various fiber composites as predicted by this equation are plotted in the figure as a function of  $S_{fT}/E_f$ . Corresponding rankings of fiber composites with 50% fiber to volume ratio normalized with respect to a boron/epoxy composite are listed in the table.

RELATIVE IMPACT RESISTANCE OF VARIOUS  
AVAILABLE FIBER COMPOSITES

Composite	Rank Relative to Boron/Epoxy Composite
Modmor-I/Epoxy	.30
ThorneI-50S/Epoxy	.33
ThorneI-75/Epoxy	.53
Boron/Epoxy	1.00
Modmor-II/Epoxy	1.04
ThorneI-400/Epoxy	1.68
PRD-49/Epoxy	1.82
E-Glass/Epoxy	3.70
UARL-344-Glass/Epoxy	8.00
S-Glass/Epoxy	10.20

In the equation (1), IED is not directly dependent on the resin properties. However, some influence of the resin properties enters the equation through  $\beta_{fT}$ .

#### Hybrid Composite Concept

Hybrid composites are usually made by laminating together plies or laminates from two different fiber/matrix systems. The equation utilizing the hybrid com-

(continued overleaf)

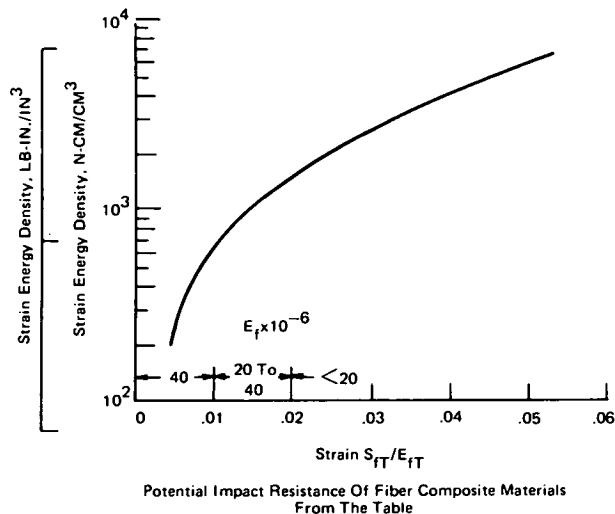
posite concept to design a cantilever, whose core and faces (shell) are made from two different fiber/matrix systems, is given by:

$$IED = \frac{1}{2} \frac{S_{l11T}^s}{E_{l11}^s} \left\{ \left[ \frac{1}{9} + \frac{1}{30} \left( \frac{h}{l} \right)^2 \left( \frac{E_{l11}^a}{G_{l12}^a} \right) \right] + \frac{1}{16N_{LD}} \left( \frac{h}{l} \right) \frac{E_{l11}^s}{S_{l12}^c} \right. \quad (2)$$

$$\left. + \frac{\pi}{16} \left( \frac{N_{fD} d_f^3}{bh} \right) \left( \frac{E_{l11}^s}{S_{l12}^s} \right) \left( \frac{S_{fT}^s}{S_{l11T}^s} \right)^2 \right\}$$

where the superscripts (a), (s), and (c) represent averaged core-shell, shell, and core, respectively. The subscript (l) refers to unidirectional composite properties along the direction indicated by the numerical subscripts following (l). The variables b, h, and (l) represent width, depth, and length of the cantilever, respectively. The variables  $d_f$ ,  $N_{fD}$  and  $N_{LD}$  represent fiber diameter, number of fibers that pulled out, and number of layers that delaminated, respectively. The variables E, S, and G denote normal modulus (compression or tension), strength, and shear modulus of the composite, respectively.

Examining this equation reveals that the shear contribution depends on  $E_{l11}^a/G_{l12}^a$ , and both fiber pull-out and delamination depend on the parameter  $E_{l11}^s/S_{l12}^s$ . This means that in order to take advantage of the high shear contribution of fiber pull-out and/or delamination,



high longitudinal modulus, low shear modulus, and low intralaminar shear strength composites should be selected. Most commercial composites containing various types of fibers in a resin matrix meet this criterion.

#### Notes:

1. These equations can be used in the design of any composite structural component subjected to impact; for example, compressor blades, pipes, wall or roof panels, and many others.
2. The longitudinal impact resistance equation can be used by designers, researchers, and fabricators of fiber composite components in selecting fibers for impact applications.
3. The hybrid composite concept can be used by designers in numerous industries such as aircraft, aerospace, marine, construction, and other commercial industries.
4. The following documentation may be obtained from:  
National Technical Information Service  
Springfield, Virginia 22151  
Single document price \$3.00  
(or microfiche \$0.95)

Reference: NASA TM-X-67802 (N71-24010), Impact Resistance of Unidirectional Fiber Composites

Reference: NASA TN-D-6463 (N71-32243), Designing for Impact Resistance with Unidirectional Fiber Composites

5. Technical questions may be directed to:  
Technology Utilization Officer  
Lewis Research Center  
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#### Patent status:

No patent action is contemplated by NASA.

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